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USSR Report

MATERIALS SCIENCE AND METALLURGY

(FOUO 4/81)

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USSR REPORT

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(FOUO 4/81)

CONTENTS

ANALYSIS AND TESTING

UDC: 539.37:620.17:620.19

EVALUATING CRACK RESISTANCE OF STRUCTURAL MATERIALS

Kiev METODY I SREDSTVA OTSENKI TRESHCHINOSTOYKOSTI KONSTRUKTSIONNYKH MATERIALOV in Russian 1981 (signed to press 12 Dec 80) pp 3-4, 301-303

[Foreword and table of contents from book "Methods and Means of Evaluating the Crack Resistance of Structural Materials", edited by V. V. Panasyuk, Izdatel'stvo "Naukova dumka", 1500 copies, 303 pages]

[Text] Contents

FOREWORD

Interest in the problem failure of materials has been steadily growing during the last two or three decades, and rapid growth and development of research is observed in this field of science. This has been caused to a significant degree by the practical importance of this problem and, in particular, its great significance for developing methods of estimating the durability of a material in a structure under given conditions of operation, as well as for forming the principles of controlling the strength of structural materials.

Intensive advance in elaboration of the problem of failure of materials became possible as a result of new approaches to treatment of this phenomenon as a phenomenon of crack formation and development, and as a result of elaboration of effective mathematical and physical methods of analysis of stressed-deformed states in a deformable solid. Of special significance in this area are new failure criteria based on the concepts of density of fracture energy, coefficients of stress intensity, critical crack opening, etc. They have become the basis of fundamentally new methodological approaches in determining the durability of structural materials under specified extreme operating conditions. These approaches have made it possible to adopt the concept of crack resistance in engineering practice, that is, the characteristics of a material's resistance to the development of cracks, as well as the values of critical and threshold coefficients of intensity of stresses, critical or maximum crack opening, diagrams of rate of crack growth during protracted cyclic or static loading, etc. The practical significance of crack resistance characteristics for engineering practice is indicated by the fact that in some technologically developed countries steps are being taken to standardized methods of determining crack resistance characteristics in order to provide adequate attestation and ranking of structural materials on the basis of resistance to crack propagation.

A new field of study of strength of materials has formed in this area -- mechanics of failure, the development of which originated in study of concentration of stresses alongside cavities and apertures in an elastic continuum. In the 1950's this area of investigation was intensively developed by scientists at the Ukrainian SSR Academy of Sciences Institute of Engineering Science and Automatic Control (presently the Ukrainian SSR Academy of Sciences Physicomechanical Institute) under the direction of Ukrainian SSR Academy of Sciences Academician G. N. Savin and Professor M. Ya. Leonov. This resulted in publication of the first studies on theory of cracks, estimate of the elastico-plastic situation at the apex of a quasi-brittle body, as well as limit equilibrium of brittle bodies with cracks. The first Soviet monograph dealing with this latter subject was published in 1968.* The now widely known δ_k criterion of limit equilibrium and crack resistance of structural materials was formulated in the first studies on theory of cracks.

Methods of estimating the effective surface fracture energy, which are something of an analog of methods of estimating the now well-known parameter of specific intensity of fracture energy G_{Ic}, were elaborated in the mid-1960's at the Ukrainian SSSR Academy of Sciences Physicomechanical Institute. A number of studies at the Institute laid down the methodological groundwork for the nonlinear criterion of failure, which is being intensively developed today, a criterion which was designated J-integral. As a result of fruitful activity by the Ukrainian SSR Academy of Sciences Physicomechanical Institute in the area of mechanics of failure, more than 200 different items were published (including monographs), in which theoretical and applied developments in this area of science are synthesized.

Taking into consideration the practical possibility of research in the area of mechanics of failure, the Institute devotes considerable attention to new methodological developments in estimating the crack resistance of structural materials, including both the development of new methods and experimental means for estimating the crack resistance of materials.

This volume presents retrospectively the most important methodological achievements in estimating a material's resistance to the propagation of cracks under the most diversified conditions of loading, results obtained in recent years at the Ukrainian SSR Academy of Sciences Physicomechanical Institute.

All articles in this volume are grouped in four sections according to methodological thrust and functional significance in estimating crack resistance. The first section contains articles which present the analytic basis of a number of new methods

* Panasyuk, V. V., "Predel'noye ravnovesiye khrupkikh tel s treshchinami" [Limit Equilibrium of Brittle Bodies With Cracks], Kiev, Naukova Dumka, 1968, 246 pages.

of estimating a material's resistance to crack propagation. Alongside establishment and and development of conditions of applicability of failure criteria, the articles in this section present calculated relations for estimating crack resistance in objects of a cylindrical type with an exterior and interior cracks, as well as in special specimens of a disk type, on which it is comparatively easy to secure stabilization of coefficients of intensity of stresses in the process of crack growth.

The second section reflects the diversified activities of the Institute's experts in creating and improving experimental methods of estimating brief-duration crack resistance (fracture toughness) of metals and alloys. These methods provide a substantial measure of experimental confirmation to the analytic solutions developed at the Institute. Some articles in this section deal with development and improvement of techniques of inducing fatigue cracks, which provide an adequate estimate of crack resistance (fracture toughness).

The third section deals with development of methods and techniques of estimating long-term crack resistance of structural materials under cyclic loading. In addition to construction and interpretation of fatigue failure diagrams, the articles describe design features and operating principles of various testing devices for studying the kinetics of crack growth under protracted cyclic loading.

The fourth section deals with the methodological aspects of the youngest and inadequately elaborated problem of mechanics of failure, pertaining to growth of cracks under the effect of static loads and aggressive media. Development of these problems is of particular engineering significance in connection with the determined radical effect on crack growth of gaseous and liquid media which are recognized as inert or low-activity in estimating the load-carrying capacity of items not containing cracklike concentrators. A characteristic feature of a number of approaches and methods described in this volume is their extensive analytic line of reasoning and practical effectiveness, which enables one to recommend them as a basis for drafting standards for determining the crack resistance of metals and alloys.

3024
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COMPOSITE MATERIALS

UDC 621.893: 620.22: 678-036

ANTIFRICTION PROPERTIES OF FLUOROPOLYMER-BASE COMPOSITION MATERIALS

Moscow ANTIFRIKTSIONNYYE SVOYSTVA KOMPOZITSIONNYKH MATERIALOV NA OSNOVE FTORPOLIMEROV in Russian 1981 pp 2-4, 146-147

[Annotation, foreword and table of contents from book "Antifriction Properties of Fluoropolymer Base Composition Materials", by N. P. Istomin and A. P. Semenov, Izdatel'stvo "Nauka", 147 pages]

[Text] Annotation

This monograph gives the results of the study of friction and wear without lubrication using fluoropolymers and fluoropolymer-base composition materials. Installations and testing methods are described. Data on various technological processes for obtaining fluoroplastic-4-base composition materials are cited. The results of the effect of a number of factors on the friction and wear of fluoropolymers, as well as of the introduction of various fillers into polymers are considered. Data are cited on the friction and wear of metal-fluoroplastic materials and fluoroplastic-4MB-base composition materials.

This book is intended for scientific staff workers, engineers and designers involved in solving problems of friction, wear and lubrication.

The book contains 14 tables and 61 illustrations. The bibliography lists 172 items.

Foreword

The use of polymer materials at friction joints had already become widespread in the thirties. At first, they were phenolic tar-base plastics such as textolite or laminated wood plastics. Then polyamide tars and their compounds with other substances appeared and began to be used as antifriction materials. All these materials are efficient only with lubrication, including lubrication with water and, under certain condition, have important advantages over metal materials.

In the fifties to the seventies, due to the development of chemistry and, in particular, the rapid development of fluorine chemistry [1-6], it became possible to obtain, on an industrial scale, a whole series of entirely new synthetic fluoropolymers. Among such materials, polytetrafluoroethylene [PTFE], or fluoroplastic-4, has a unique complex of properties. One of the most valuable properties of fluoroplastic-4 is that its friction coefficient with other materials without lubrication and with fluoroplastic-4 itself is low (at low sliding velocity it does not exceed 0.05). It was precisely because of this property that fluoroplastic-4 is being used as an antifriction material; however, in its pure form it has limited application because of its low wear resistance and low mechanical properties. The "inherent" antifriction properties of fluoroplastic-4, however, may be used in various methods including creating composition materials on its basis whose friction coefficients remain close to those of pure fluoroplastic-4, while the wear resistance when operating without lubrication is increased many times and, at the same time, other physico-mechanical properties (strength, heat conductivity etc.) necessary for bearing materials are improved.

The development and introduction of increasing scales of antifriction materials not requiring lubrication are urgent problems in modern and future technology. The possibility of operating individual machine units and entire machines without lubrication is very desirable in the majority of cases, while in some cases -- extremely necessary. This makes it possible to save large amounts of lubrication materials, simplifies machine design, reduces operating costs and facilitates an increase in production efficiency. In a number of cases, these materials are the single acceptable solution of the problems faced by designers.

The development of new materials able to operate without lubrication, and the improvement of materials already available, are impossible without corresponding investigations of, and finding methods for increasing wear resistance and improving the antifriction properties of materials by improving their composition and the technology for their manufacture.

In this book being offered to the reader, the results are correlated of investigations made at the USSR Academy of Sciences Machinery Science Institute imeni A. A. Blagonravov on friction and wear without lubrication of fluoroplastic-4 and composition materials on its basis. The results of broad investigations are given, using a single method, of the effects of velocity, load, temperature, degree of crystallization; the action of penetrating radiation on friction and the wear of fluoroplastic-4 without fillers, as well as the effect of composition materials on antifriction properties based on fluoroplastic-4 with fillers (their chemical nature, composition, concentration, degree of dispersion, shape of particles and their orientation), and the technological processes for obtaining these composition materials. Besides fluoroplastic-4 and its compositions with various fillers, several other fluoropolymers were investigated and the possibility of utilizing them to obtain antifriction materials that operate without lubrication was considered.

On the basis of the obtained results, a number of governing laws were established that make it possible to select better substantiated fillers and technological processes to obtain materials (on the basis of fluoropolymers) with a given complex of properties that have a wear resistance hundreds and thousands of times greater than fluoroplastic-4 for concrete operating conditions.

The authors are grateful to Z. M. Yermakova and P. G. Babicheva who participated in making the tests and processing the results. The authors honor the memory of professor M. M. Khrushchev, doctor of technical sciences, who initiated the investigations, the results of which are given in this monograph.

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2291
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HEAT RESISTANT ALLOYS

UDC: 669.14.018.44:539.4

HEAT RESISTANCE OF ALLOYS FOR GAS TURBINE ENGINES

Moscow ZHAROPROCHNOST' SPLAVOV DLYA GAZOTURBINNYKH DVIGATELEY in Russian 1981 (signed to press 22 Oct 80) pp 3-6

[Table of contents, foreword and introduction from book "Heat Resistance of Alloys for Gas Turbine Engines", by Radiy Yevgen'yevich Shalin, Igor' Petrovich Bulygin, and Yevgeniy Rostislavovich Golubovskiy, Izdatel'stvo "Metallurgiya", 1,500 copies, 120 pages]

[Text] Table of Contents

FOREWORD

Improving the efficiency of societal production is a most important direction of party economic and technical policy advanced at the 25th CPSU Congress. One of the principal ways to achieve this objective, specified in party and government decisions, is to reduce the materials input in industrial products and securement of high product quality by extensive employment of advanced design solutions and proper utilization of materials, including ferrous and nonferrous metals and alloys, on the basis of a comprehensive, objective and precise evaluation of their properties.

Advance in the machine building industry is accompanied by speeding up the pace of improvement in operating parameters and increasing the load on structural components, with simultaneous increase in demands on product reliability and service life. In order to meet these demands it is essential to develop new, improved methods of evaluating the strength, reliability and durability of metallic materials produced by the metallurgical industry, with the objective of maximum utilization of their capabilities.

Several current tasks pertaining to this important problem, as applied to heat resistant alloys for a leading and intensively developing branch of power engineering machine building -- transport gas turbine engineering, are examined in this volume.

INTRODUCTION

Increasing demands on reliability and service life of gas turbine engines simultaneously with an improvement in their operating parameters evokes the necessity of developing optimal methods of estimating the strength properties of employed materials, with the objective of their fullest and most correct utilization. The basic criteria of properties of materials intended for extended operation at high temperatures include long-time strength and creep limit indices, utilized as calculated performance characteristics.

Extensive adoption of any grade of steel or alloy presupposes the manufacture of components of metal from different melts. Therefore in determining service life and margin of safety for commercial metal, the design engineer is interested not only in the average heat resistance indices of certain typical melts but also the performance of the target material as a whole (that is, grade characteristics), including standard deviation of strength properties and change in this figure in relation to length of service and level of operating temperature.

A lag in acquisition of information on the durability of materials in conditions of extended effect of stress-strain loads and high temperature, connected to a considerable degree with a substantial volume and considerable duration of laboratory testing for heat resistance, creates difficulties for design engineers and slows the rate of increase of product durability. In connection with this, development of reliable methods of predicting long-time strength and creep limit indices on the basis of the temperature-time relations of these indices and taking their variance into account, in spite of extensive research in this area remains a critical problem.

Questions connected with development and practical adoption of methods of statistical estimate and prediction of long-time strength and creep limit characteristics (including plasticity limit) are of particular importance for the class of high-heat-resistant alloys employed for power components of transport (especially aviation) gas turbine engines (GTE), for the following reasons:

increased demands on reliability of critical structural components;

high thermal and mechanical stress on parts;

limited design and development timetable and rapid product replacement;

continuous increase in service life;

specific features of this class of materials.

The last of the above-listed factors is of great importance in regard to the problems under discussion.

For the most part complex nickel-base heterophase alloys with a clearly-marked structural instability in the range of operating temperatures are presently employed in the manufacture of such GTE components as turbine wheels and blades. Also characteristic of these alloys is a variability of manufacturing technology, caused by improvement in manufacturing processes [1] and variation in heat treatment of specific semimanufactures and finished products. In this case one can expect reliable results only with a statistical approach to estimating heat resistance characteristics and employment of temperature-time (temperature-power) relations which reflect the structural features of a material for predicting these characteristics.

At the same time melts of this class, and especially the group of new high-heat-resistant foundry alloys of the ZhS family which head this class, a typical representative of which is the ZhS6U alloy [2], which is produced in quantity, are the most interesting and representative objects of investigation in connection with the above features.

The developmentof new engines involves the adoption of cooled turbine moving and nozzle blades. In this area casting alloys are for all practical purposes displacing forming alloys, since they possess greater resistance and provide a better capability to produce hollow cooled blades.

In this volume the authors examine the methods and practical results of solving a number of basic problems pertaining to statistical estimation and prediction of long-time strength and creep limit indices of high-heat-resistant alloys employed in propulsion engineering.

3024
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UDC 669.2/8:3621.7+669.2/8.017/

PROCESSING LIGHTWEIGHT AND HEAT-RESISTANT ALLOYS

Moscow PROTSESSY OBRABOTKI LEGKIKH I ZHAROPROCHNYKH SPLAVOV in Russian 1981
pp 2, 5-6, 260-262

[Annotation, table of contents, and foreword from book "Processing of Lightweight and Heat-Resistant Alloys", edited by Academician N. M. Zhavoronkov, Izdatel'stvo "Nauka", 262 pages]

[Text] This volume extensively discusses the scientific and technical school developed by Academician A. F. Belov, who celebrates his 75th birthday in 1981, by his students and disciples. This volume contains the results of most recent investigations in the area of casting, pressure shaping and heat treatment of aluminum, magnesium, titanium, heat-resistant and refractory alloys; contemporary problems of physical metallurgy, metallurgy and processing technology are examined. This volume contains extensive materials dealing with obtaining metal blanks and workpieces by methods of high-speed crystallization and hot isostatic pressure forging.

This volume is intended for research scientists, design engineers and metallurgical production specialists, physical metallurgists, process engineers, designers, machine builders, and students in the appropriate fields of specialization.

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FOREWORD

This volume extensively discusses the scientific and technical innovations in metallurgy of lightweight and heat-resistant alloys developed by Academician Aleksandr Fedorovich Belov, who is celebrating his 75th birthday in 1981, and by his pupils and disciples.

The first section of this volume deals with general problems of treatment and working of lightweight and heat-resistant alloys. Prominent Soviet scientists -- metallurgists, physical metallurgists, machine builders, and experts in the field of powder metallurgy -- outline, on the basis of analysis of the present level of science and technology in high-grade metallurgy, the general paths of further development of advanced processes of working and treatment of metals and the development of equipment for processing lightweight and heat-resistant alloys with utilization of high pressures and temperatures. Also presented are the results of physical metallurgical investigations and studies in the area of theory of pressure shaping metals, which are of interest in studying the processes of working all alloys.

The second section of this volume deals with aluminum and magnesium alloys. It contains articles which encompass a broad range of questions, including improvement in production technology and product quality at aluminum industry enterprises, development prospects of the processes of blank casting, cold rolling, continuous processes of heat treatment and application of protective and decorative coatings on semimanufactures of aluminum alloys. Articles examine the results of investigations of change in structure and properties in relation to the chemical composition of alloys and the conditions of various treatment processes; data are presented on the nature of fracture of alloys. Materials are included which deal with obtaining aluminum alloys by the high-speed crystallization method and this method's development prospects; various aspects of the quality of magnesium alloys are examined. Information is presented on the prospects of utilization of aluminum alloys in the nation's economy.

The third section of this volume deals with investigations of titanium and heat-resistant alloys based on nickel and other nonferrous metals, as well as refractory metals. Of greatest interest are data pertaining to new methods of obtaining advanced metallic materials by the high-speed crystallization and hot isostatic pressure forging methods. Articles examine the complex physicochemical processes which take place during production and treatment of individual granules, during sintering of granules under the effect of high pressures and temperatures, and heat treatment of forming one-piece items. There is extensive discussion of investigation of various methods of obtaining and processing semimanufactures of titanium alloys, industrial processes of working and treating titanium, and the behavior of titanium parts in certain structures. This section contains materials pertaining to the physical metallurgy of molybdenum and tungsten.

On the whole the volume contains a good deal of new information in the area of processes of working and treating lightweight and heat-resistant alloys and points out the paths of future development of high-grade metallurgy. This volume will help further strengthen links between research scientists and industry and will promote effective utilization of scientific advances.

3024
CSO: 1842/149

MECHANICAL PROPERTIES

UDC: 620.1.05:620.17

STRENGTH, PLASTICITY OF MATERIALS IN RADIATION FLUXES

Kiev PROCHNOST' I PLASTICHNOST' MATERIALOV V RADIATSIONNYKH POTOKAKH in Russian 1979 (signed to press 12 Dec 79) pp 3-4, 283-284

[Foreword and table of contents from book "Strength and Plasticity of Materials in Radiation Fluxes", by Georgiy Stepanovich Pisarenko and Vladimir Nikolayevich Kiselevskiy, Izdatel'stvo "Naukova dumka", 1400 copies, 284 pages]

[Text] Table of Contents

FOREWORD

The development of nuclear power engineering makes it necessary to elaborate the scientific principles of strength calculations of structural components of the cores of nuclear reactors, and particularly the fuel elements, which determine the overall reliability and economy of reactors. Utilization of the reserve capability of materials able to resist loads under the complex conditions of thermal and radiation effects is possible only with availability of scientifically substantiated standards for calculating the components of the appropriate structures.

Modern technology of designing fuel elements calls for comprehensive investigation of the physicomechanical properties of fuel compositions and shell materials, as well as testing both of individual fuel element components and assemblies (for example, shells, ceramic plugs, rods, pellets, etc), and of structures as a whole in the form of fuel elements and their assemblages [131].

In the period 1955-1975 radiation materials science took shape as an independent science, which has had appreciable success in solving theoretical and applied problems of physics of radiation damage, and development of new materials possessing the requisite aggregate of physicomechanical properties. The obtained results enable one to resolve problems of application of individual types of materials under specified operating conditions.

In the development of given structures, the stressed-deformed state and the maximum load-carrying capacity of their components at the given stage of development of strength physics should be calculated from the position of mechanics of a continuous medium, which is at an early stage of development for bodies sustaining radiation damage in the process of deformation.

Equations of the state of materials constructed on the basis of continuum mechanics, applicable to the applied aspects of mechanics of materials, are formulated by synthesizing the results of tests under conditions maximally approximating actual operating conditions. Investigation directly in radiation fluxes for the purpose of obtaining initial information on the behavior of irradiated materials under various conditions of thermomechanical effect involve substantial methodological difficulties, which impede the acquisition of corresponding equations of state.

In connection with this, there exists a certain indefiniteness in establishing the dimensions and shapes of fuel elements, an uncertainty which does not guarantee optimal initial models, which are subjected to subsequent fairly complex elaboration. The lack of scientifically substantiated strength standards requires adoption of large safety factors in calculations, which as a rule leads to a decrease in the neutron-physical characteristics of reactors, greater cost and, as a consequence, decreased technical-economic indices of nuclear equipment and power generating units as a whole. Therefore investigations of the properties of irradiated materials from the standpoint of mechanics of a continuous medium are conducted for the purpose of determining not only strength and plasticity characteristics but also the patterns of change in resistance to deformation and failure in relation to conditions of irradiation, type of stressed state, nature of application of load, temperature and other factors. Conduct of research as formulated above requires execution of special programs differing from the conventional programs of radiation of materials science.

In this study an attempt is made to resolve fundamental problems of methodology of in-reactor investigations of the mechanical properties of structural materials and synthesis of data on the influence of radioactive irradiation on the various characteristics of their resistance to deformation and failure, with the aim of establishing a number, kept within reasonable limits, of independent variables in the equations of state of materials under conditions of irradiation. A phenomenological model of creep of irradiated steels is presented, as well as a criterion of their maximum load-carrying capacity in a complex stressed state.

The methodological elaborations and research results presented in this monograph were obtained by the staff of the Ukrainian SSR Academy of Sciences Institute of Problems of Strength, under the supervision of and with the participation of the authors. In particular, the data examined in Section 3 of Chapter One and Section 1 of Chapter Two were obtained with the active participation of D. V. Polevoy and O. N. Yudin; Section 3 of Chapter One and Section 2 of Chapter Two -- V. K. Lukashev and G. P. Khristov; Section 4 of Chapter One and Section 4 of Chapter Two -- Yu. D. Skripnik; Section 5 of Chapter Two -- S. S. Tishchenko; Section 2 of Chapter Five -- B. D. Kosov and O. N. Yudin. The authors would like to express their profound gratitude to these contributors.

3024
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REFRACTORY MATERIALS

UDC 669.017 669.015 + 539.4

PRECIPITATION HARDENING OF HIGH-MELTING METALS

Moscow DISPERSIONNOYE UPROCHNENIYE TUGOPLAVKIKH METALLOV in Russian 1980 (signed to press 26 Sep 80) pp 2-5, 303

[Annotation, introduction and table of contents from book "Precipitation Hardening of High-Melting Metals", by Vsevolod Konstantinovich Grigorovich and Yelena Naumovna Sheftel', edited by Professor O. A. Bannykh, doctor of technical sciences, Izdatel'stvo "Nauka", 1400 copies, 304 pages]

[Text] Annotation

An analysis of the crystalline structure and the physical and strength properties of transition metals that are the basis of most refractory alloys was made. This analysis was made from the standpoint of the electronic structure and chemical bond theory. The electronic-crystalline structure and the thermodynamic characteristics of high-melting compounds and their selection as precipitation-hardening phases are considered.

The physico-chemical principles of developing refractory alloys by combining a solid solution and precipitation hardening, as well as various methods for obtaining such refractory materials are described.

Patterns are considered of the precipitation hardening of niobium, vanadium, tantalum, chromium, molybdenum, tungsten and their alloys with high-melting carbides, nitrides and oxides of the transition metals of the fourth group.

This book is intended for a broad group of metal scientists, metallurgists, metal-physics scientists and production people who develop and use refractory materials in new areas of technology. It may be useful to students, graduate students and instructors in corresponding fields.

The book has 44 tables and 123 illustrations. The bibliography contains 563 titles.

Introduction

The development of nuclear power engineering, aviation and space technology, radio-electronics, power and chemical machine-building, metallurgy and other sectors of industry demand the development of new refractory and heat-resistant materials that are more efficient than the steel and nickel alloys used widely at the present time. The most important, still unused, reserve of high-temperature structural materials are high-melting OTsK [Body-centered cubic] metals of the V - VI groups.

Exhaustive monographs by Soviet scientists are devoted to the metal science of vanadium, niobium, molybdenum, tungsten, chromium and their alloys [1-4 et al]. The physico-chemical principles of developing refractory alloys in connection with the phase (equilibrium) diagram, based on the teachings of academician N. S. Kurnakov were developed in correlating papers [5-8]. The structure and properties of high-melting metals and their alloys were considered in detail in monographs [9-12]. The theory and practice of the precipitation hardening of iron, nickel and cobalt were also described systemically [13-15]. However, the precipitation hardening of high-melting metals, which is the most important method for raising the heat-resistance of their alloys is still not adequately covered. The investigations of precipitation hardening of metals with carbides, nitrides, oxides and borides of the transition metals, published in periodicals, were analyzed in detail from the standpoint of metal science [11]; however, a systemization and further correlation of available data in the aspect of the electronic structure and physio-chemical alloy analysis are needed. This monograph attempts to fill this blank.

The stability of the crystalline structure, the thermodynamic and mechanical strength and heat resistance of high-melting metals are determined ultimately by interatomic bonds. The formation of strong, short metallic bonds between the closest atoms in tightly packed rows is considered a result of the overlapping of orbits of the outer collectivized electrons. In this case, the electron distribution in the actual lattice space that preserves the criteria of symmetry conforming to the atomic s-, p- and d- orbits or electronic clouds, corresponds to the s-,p- and d-zones. The excitation and fission of the basic p- framework shells lead to the formation of six covalent bonds localized on the framework and the OTsK structure of the high-melting metals. Assuming the symmetry of the outer collectivized framework of localized electrons, the following can be given a simple physical interpretation: the patterns of forming crystalline structures of metals and their polymorphic transformations, the preferred system of sliding at plastic deformation, the anisotropy of elastic modules, and many physical and mechanical properties of the metals. Such an analysis of the structure and properties of high-melting OTsK metals made it possible to interpret the patterns of the formation of the alloys of these metals in the aspect of the electronic structure.

The crystalline structure and properties of hardening phases and, especially, of high-melting, high-modulus carbides, nitrides, oxides and borides of transition metals are also due to the electronic structure of their atoms and the physical nature of interatomic bonds. The extremely high strength of the lattice of these compounds -- the extremely high temperatures of melting, heat of formation, extremely high hardness and strength -- are the direct result of the formation of strong, short covalent metal-interstitial element bonds that originate due to the overlapping framework shells of the ions. The metallic bonds between adjacent atoms, originating in the metal sublattice, add strength to the structure of such compounds. Carbides, nitrides, oxides and borides of the IV group of metals play an especially important role in the precipitation hardening of the V-VI group of metals.

Precipitation-hardened metals may be obtained by powder and granular metallurgy, by chemothermal treatment as well as by metallurgical methods used especially widely at present in making high-melting metal alloys.

Of all the physico-chemical hardening principles for high-melting metals, the most important are solid solution hardening of the metal base and increasing its strength by precipitated particles. The solid solution hardening of the OTsK metals in the high temperature region is facilitated by alloying with higher-melting metals that increase the melting temperature and the electron concentration of the alloy. The most efficient was the precipitation hardening of high-melting metals by high strength carbides, nitrides, oxides and borides of the IV-V group of metals that have the highest thermodynamic stability and strength. A rational basis for developing heat-resistant alloys may be a triple system consisting of metals of the V and VI group - a metal of the IV group-interstitial element, where the V-VI group metals are the basic components, while the high-melting compound $Me_{IV}X$ is the hardening phase that forms with it a quasi-binary eutectic system. The variable solubility of the compound in the matrix makes it possible to achieve by thermal treatment the precipitation hardening of the deformed alloys, and with a higher content of the hardening phase, up to the eutectic concentration -- to obtain high strength casting alloys.

Among the most high-melting metals, niobium is especially promising for developing heat-resistant alloys. It is distinguished by high plasticity, relatively low oxidizability and other useful characteristics. On the basis of new theoretical and experimental data, the possibility of efficient hardening of niobium and its alloys by precipitating particles of carbides, nitrides and zirconium and hafnium oxides was discovered. The patterns of forming and decomposing supersaturated solid solutions in two-phase niobium alloys is typical for the classical aging of alloys. In this connection, it is very important to be able to regulate the structure and properties of these alloys by thermal treatment. The combination of the optimal amount of precipitation hardening, phase and a rational mode of thermal treatment makes it possible to increase considerably the heat-resistance properties of modern niobium alloys.

On the basis of the phase (equilibrium) diagrams, and in connection with the physico-chemical theory of heat-resistance, it was found to be possible to systematize rationally a great amount of data on the precipitation hardening of vanadium, tantalum, chromium, molybdenum and tungsten alloys by high-melting compounds of group IV metals, as well as by niobium and tantalum compounds. Chapters 1 and 3 were written by V. K. Grigorovich and 2, 4, 5 -- by Ye. N. Sheftel'.

The authors express their deep gratitude to professor O. A. Bannykh, doctor of technical sciences, for his scientific editing of the book and very useful discussion of its basic concepts; K. P. Gurov, doctor of physico-mathematical sciences; O. G. Karpinskiy, candidate of physico-mathematical sciences; A. I. Kozlenkov, candidate of physico-mathematical sciences for their discussion of questions touched upon in the book on the physics of metals; as well as to V. M. Blinov and other staff members of the institute for their valuable comments. The authors are grate-ul to G. Sh. Usmanova and L. I. Tsyganova for their help in preparing the manuscript.

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